

CHAPTER 11

MACHINE ELEMENTS AND BASIC MECHANISMS

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Describe the machine elements used in naval machinery and equipment.*
 - *Identify the basic machines used in naval machinery and equipment.*
 - *Explain the use of clutches.*
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Any machine, however simple, consists of one or more basic machine elements or mechanisms. In this chapter we will take a look at some of the more familiar elements and mechanisms used in naval machinery and equipment.

BEARINGS

Friction is the resistance of force between two surfaces. In chapter 7 we saw that two objects rubbing against each other produce friction. If the surfaces are smooth, they produce little friction; if either or both are rough, they produce more friction. To start rolling a loaded hand truck across the deck, you would have to give it a hard tug to overcome the resistance of static friction. To start sliding the same load across the deck, you would have to give it an even harder push. That is because rolling friction is always less than sliding friction. We take advantage of this fact by using rollers or bearings in machines to reduce friction. We use lubricants on bearing surfaces to reduce the friction even further.

A bearing is a support and guide that carries a moving part (or parts) of a machine. It maintains the proper relationship between the moving part or parts and the stationary part. It usually permits only one form of motion, such as rotation. There are two basic types of bearings: sliding (plain bearings), also called friction or

guide bearings, and antifrictional (roller and ball bearings).

SLIDING BEARINGS

In sliding (plain) bearings, a film of lubricant separates the moving part from the stationary part. Three types of sliding bearings are commonly used: reciprocal motion bearings, journal bearings, and thrust bearings.

Reciprocal Motion Bearings

Reciprocal motion bearings provide a bearing surface on which an object slides back and forth. They are found on steam reciprocating pumps, in which connecting rods slide on bearing surfaces near their connections to the pistons. We use similar bearings on the connecting rods of large internal-combustion engines and in many mechanisms operated by cams.

Journal Bearings

Journal bearings guide and support revolving shafts. The shaft revolves in a housing fitted with a liner. The inside of the liner, on which the shaft bears, is made of babbitt metal or a similar soft alloy (antifriction metal) to reduce friction. The soft metal is backed by a bronze or copper layer and has a steel back for strength. Sometimes the bearing is made in two halves and is

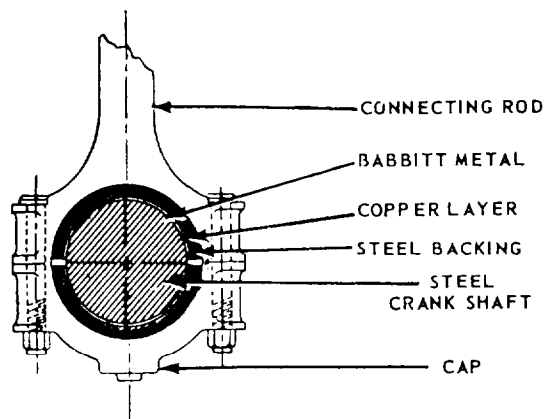


Figure 11-1.-Babbitt-lined bearing in which steel shaft revolves.

clamped or screwed around the shaft (fig. 11-1). We also call it a laminated sleeve bearing.

Under favorable conditions the friction in journal bearings is remarkably small. However, when the rubbing speed of a journal bearing is very low or extremely high, the friction loss may become excessive. A good example is the railroad car. Railroad cars are now being fitted with roller bearings to eliminate the "hot box" troubles associated with journal bearings.

Heavy-duty bearings have oil circulated around and through them. Some have an additional cooling system that circulates water around the bearing. Although revolving the steel shaft against babbitt metal produces less friction (and less heat and wear) than steel against

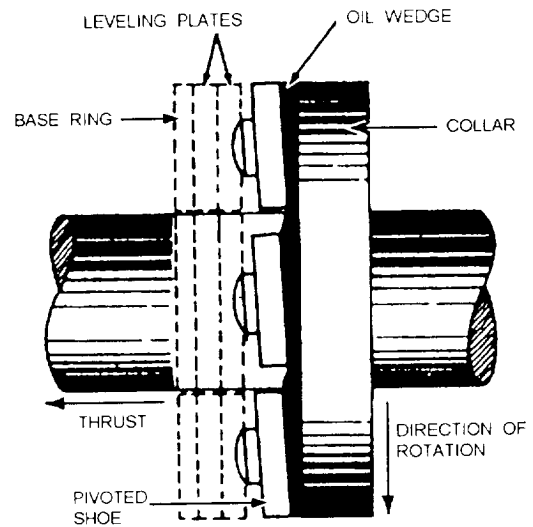


Figure 11-3.-Diagrammatic arrangement of a Kingsbury thrust bearing, showing oil film.

steel, keeping the parts cool is still a problem. The same care and lubrication needed to prevent a burned out bearing on your car is needed on all Navy equipment, only more so. Many lives depend on the continued operation of Navy equipment.

Thrust Bearings

Thrust bearings are used on rotating shafts, such as those supporting bevel gears, worm gears, propellers, and fans. They resist axial thrust or force and limit axial

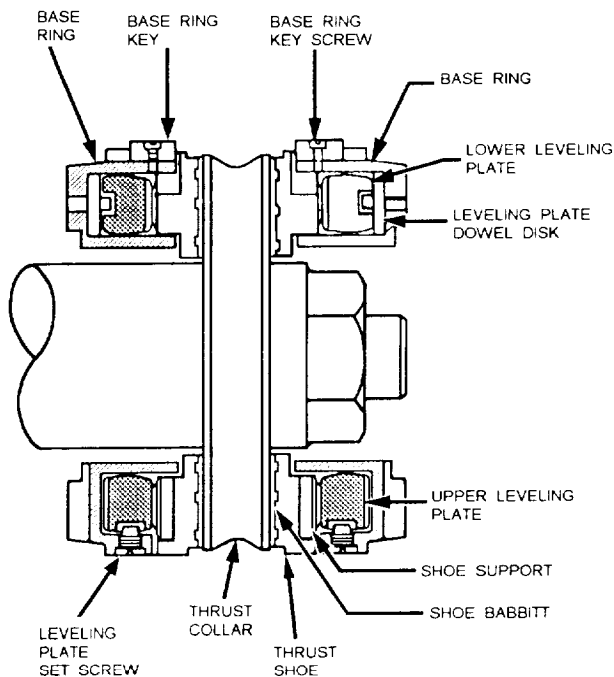
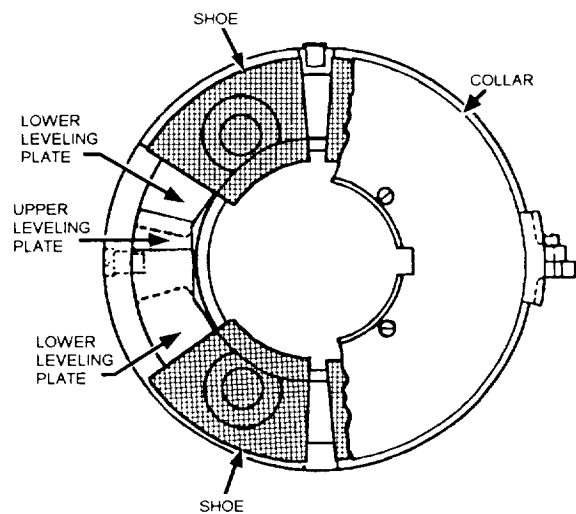


Figure 11-2.-Kingsbury pivoted-shoe thrust bearing.



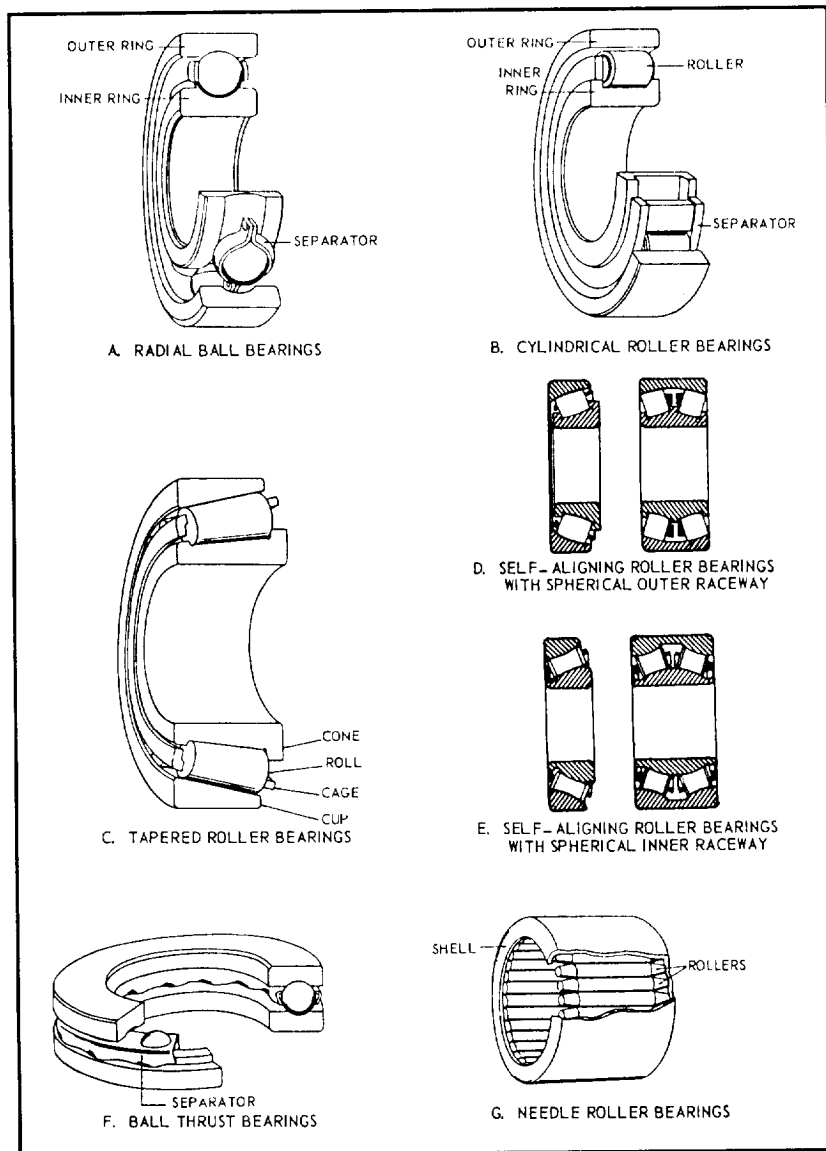


Figure 11-4. The seven basic types of antifrictional bearings.

movement. They are used chiefly on heavy machinery, such as Kingsbury thrust bearings used in heavy marine-propelling machinery (figs. 11-2 and 11-3). The base of the housing holds an oil bath, and the rotation of the shaft continually distributes the oil. The bearing consists of a thrust collar on the propeller shaft and two or more stationary thrust shoes on either side of the collar. Thrust is transmitted from the collar through the shoes to the gear housing and the ship's structure to which the gear housing is bolted.

ANTIFRICTIONAL OR ROLLER AND BALL BEARINGS

You have had first-hand acquaintance with ball bearings since you were a child. They are what made

your roller skates or bicycle wheels spin freely. If any of the little steel balls came out and were lost, your roller skates screeched and groaned.

Antifrictional balls or rollers are made of hard, highly polished steel. Typical bearings consist of two hardened steel rings (called races), the hardened steel balls or rollers, and a separator. The motion occurs between the race surfaces and the rolling elements. There are seven basic types of antifrictional bearings (fig. 11-4):

1. Radial ball bearings
2. Cylindrical roller bearings
3. Tapered roller bearings

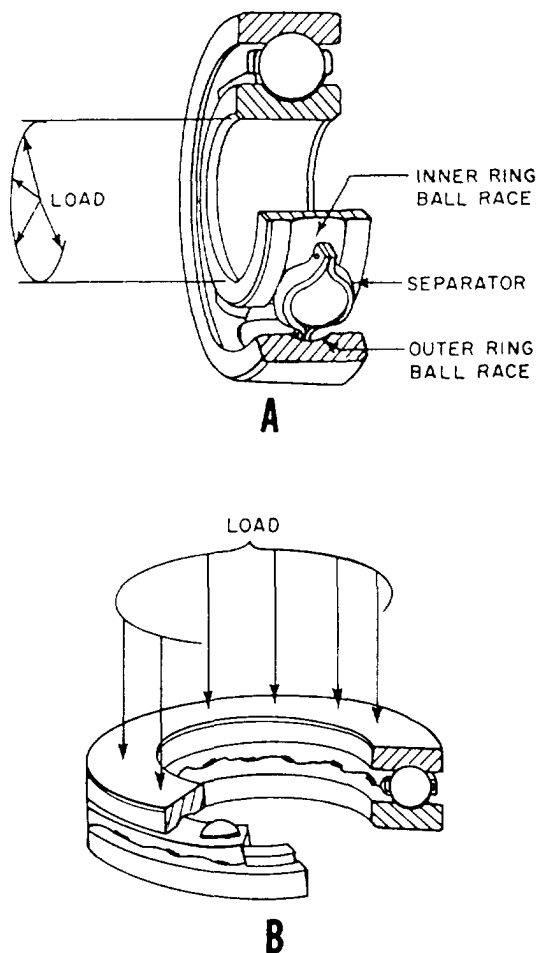


Figure 11-5.-Ball bearings. A. Radial type; B. Thrust type.

4. Self-aligning roller bearings with a spherical outer raceway
5. Self-aligning roller bearings with a spherical inner raceway
6. Ball thrust bearings
7. Needle roller bearings

Roller bearing assemblies are usually easy to disassemble for inspection, cleaning, and replacement of parts. Ball bearings are assembled by the manufacturer and are installed, or replaced, as a unit. Sometimes maintenance publications refer to roller and ball bearings as either thrust or radial bearings. The difference between the two depends on the angle of intersection between the direction of the load and the plane of rotation of the bearing.

Figure 11-5, A, shows a radial ball bearing assembly. The load shown is pressing outward along the radius of the shaft. Now suppose a strong thrust were to be exerted on the right end of the shaft in an effort to

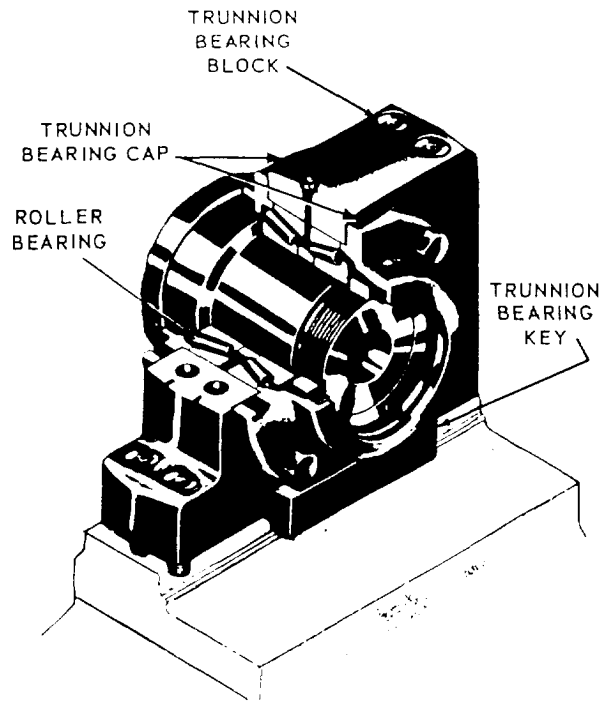


Figure 11-6.-Radial-thrust roller bearing.

move it to the left. You would find that the radial bearing is not designed to support this axial thrust. Even putting a shoulder between the load and the inner race wouldn't support it; instead, the bearings would pop out of their races.

Supporting a thrust on the right end of the shaft would require the thrust bearing arrangement of the braces shown in figure 11-5, B. A shoulder under the lower race and another between the load and the upper race would handle any axial load up to the design limit of the bearing.

Sometimes bearings are designed to support both thrust and radial loads. This explains the use of the term "radial thrust" bearings. The tapered roller bearing in figure 11-6 is an example of a radial-thrust roller bearing.

Antifriction bearings require smaller housings than other bearings of the same load capacity and can operate at higher speeds.

SPRINGS

Springs are elastic bodies (generally metal) that can be twisted, pulled, or stretched by some force. They can return to their original shape when the force is released. All springs used in naval machinery are made of metal—usually steel—though some are made of phosphor bronze, brass, or other alloys. A part that is subject to constant spring thrust or pressure is said to be

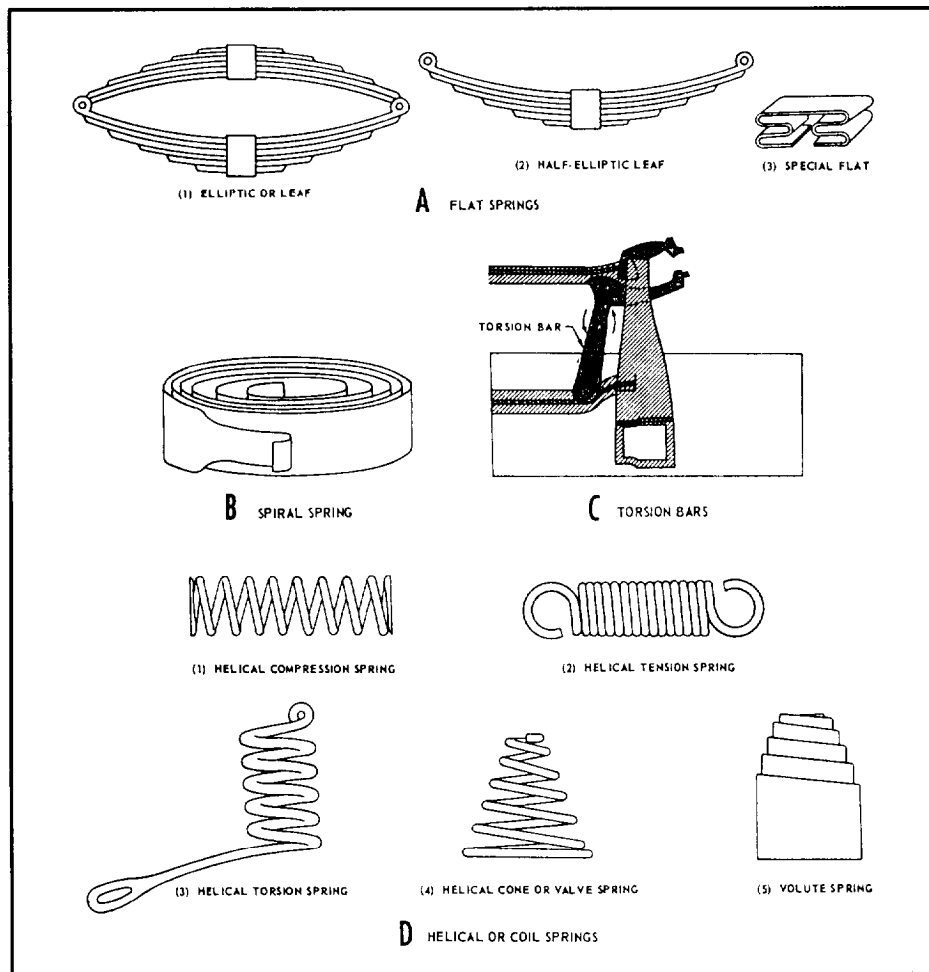


Figure 11-7.-Types of springs.

spring-loaded. (Some components that appear to be spring-loaded are actually under hydraulic or pneumatic pressure or are moved by weights.)

FUNCTIONS OF SPRINGS

Springs are used for many purposes, and one spring may serve more than one purpose. Listed below are some of the more common of these functional purposes. As you read them, try to think of at least one familiar application of each.

1. To store energy for part of a functioning cycle.
2. To force a component to bear against, to maintain contact with, to engage, to disengage, or to remain clear of some other component.
3. To counterbalance a weight or thrust (gravitational, hydraulic, etc.). Such springs are usually called equilibrator springs.
4. To maintain electrical continuity.

5. To return a component to its original position after displacement.
6. To reduce shock or impact by gradually checking the motion of a moving weight.
7. To permit some freedom of movement between aligned components without disengaging them. These are sometimes called take-up springs.

TYPES OF SPRINGS

As you read different books, you will find that authors do not agree on the classification of types of springs. The names are not as important as the types of work they do and the loads they can bear. The three basic types are (1) flat, (2) spiral, and (3) helical.

Flat Springs

Flat springs include various forms of elliptic or leaf springs (fig. 11-7, A [1] and [2]), made up of flat or

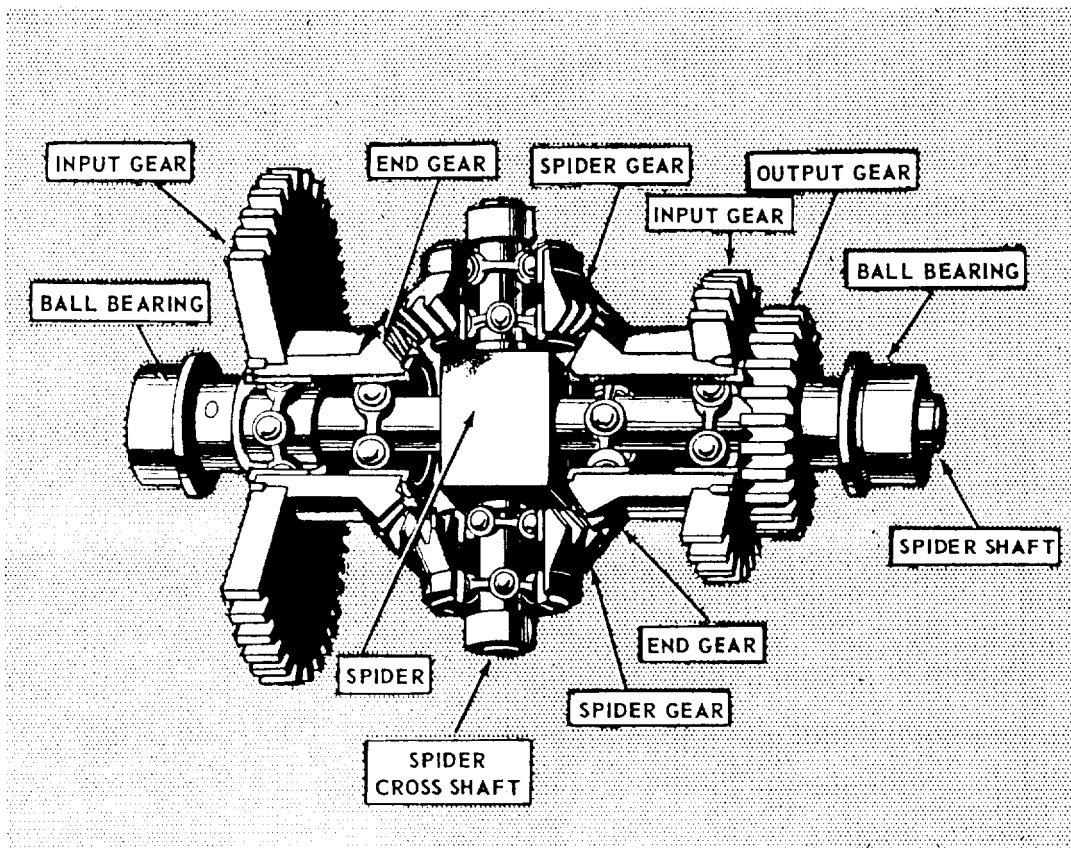


Figure 11-8.-Bevel gear differential.

slightly curved bars, plates, or leaves. They also include special flat springs (fig. 11-7, A [3]), made from a flat strip or bar formed into whatever shape or design best suited for a specific position and purpose.

Spiral Springs

Spiral springs are sometimes called clock, power (11-7, B), or coil springs. A well-known example is a watch or clock spring; after you wind (tighten) it, it gradually unwinds and releases power. Although other names for these springs are based on good authority, we call them "spiral" in this text to avoid confusion.

Helical Springs

Helical springs, also often called spiral (fig. 11-7, D), are probably the most common type of spring. They may be used in compression (fig. 11-7, D [1]), extension or tension (fig. 11-7, D [2]), or torsion (fig. 11-7, D [3]). A spring used in compression tends to shorten in action,

while a tension spring lengthens in action. Torsion springs, which transmit a twist instead of a direct pull, operate by a coiling or an uncoiling action.

In addition to straight helical springs, cone, double-cone, keg, and volute springs are classified as helical. These types of springs are usually used in compression. A cone spring (11-7, D [4]), often called a valve spring because it is frequently used in valves, is formed by wire being wound on a tapered mandrel instead of a straight one. A double cone spring (not illustrated) consists of two cones joined at the small ends, and a keg spring (not illustrated) consists of two cone springs joined at their large ends.

Volute springs (fig. 11-7, D [5]) are conical springs made from a flat bar that is wound so that each coil partially overlaps the adjacent one. The width (and thickness) of the material gives it great strength or resistance.

You can press a conical spring flat so that it requires little space, and it is not likely to buckle sideways.

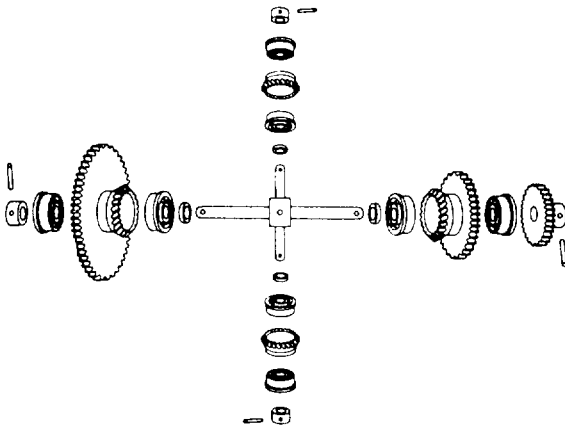


Figure 11-9.-Exploded view of differential gear system.

Other Types of Springs

Torsion bars (fig. 11-7, C) are straight bars that are acted on by torsion (twisting force). The bars may be circular or rectangular in cross section. They also may be tube shaped; other shapes are uncommon.

A special type of spring is a ring spring or disc spring (not illustrated). It is made of several metal rings or discs that overlap each other.

THE GEAR DIFFERENTIAL

A gear differential is a mechanism that is capable of adding and subtracting mechanically. To be more precise, we should say that it adds the total revolutions of two shafts. It also subtracts the total revolutions of one shaft from the total revolutions of another shaft—and delivers the answer by a third shaft. The gear differential will continuously and accurately add or subtract any number of revolutions. It will produce a continuous series of answers as the inputs change.

Figure 11-8 is a cutaway drawing of a bevel gear differential showing all of its parts and how they relate to each other. Grouped around the center of the mechanism are four bevel gears meshed together. The two bevel gears on either side are “end gears.” The two bevel gears above and below are “spider gears.” The long shaft running through the end gears and the three spur gears is the “spider shaft.” The short shaft running through the spider gears together with the spider gears themselves make up the “spider.”

Each spider gear and end gear is bearing-mounted on its shaft and is free to rotate. The spider shaft connects

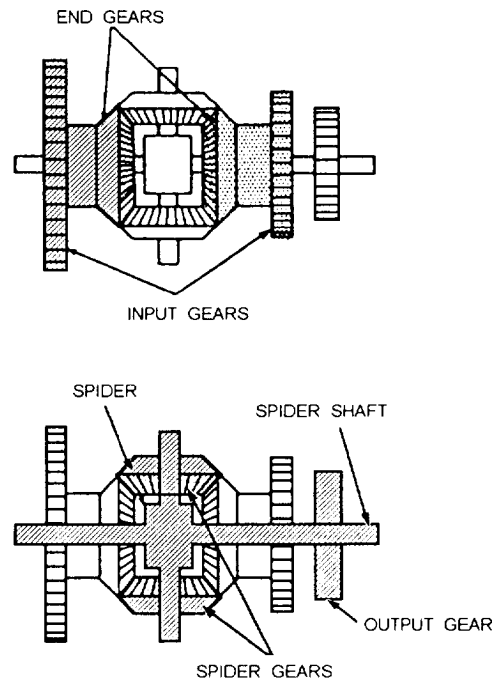


Figure 11-10.-The differential. End gears and spider arrangement.

with the spider cross shaft at the center block where they intersect. The ends of the spider shaft are secured in flanges or hangers. The spider cross shaft and the spider shaft are also bearing-mounted and are free to rotate on their axis. Therefore, since the two shafts are rigidly connected, the spider (consisting of the spider cross shaft and the spider gears) must tumble, or spin, on the axis of the spider shaft.

The three spur gears, shown in figure 11-8, are used to connect the two end gears and the spider shaft to other mechanisms. They may be of any convenient size. Each of the two input spur gears is attached to an end gear. An input gear and an end gear together are called a “side” of a differential. The third spur gear is the output gear, as designated in figure 11-8. This is the only gear pinned to the spider shaft. All the other differential gears, both bevel and spur, are bearing-mounted.

Figure 11-9 is an exploded view of a gear differential showing each of its individual parts. Figure 11-10 is a schematic sketch showing the relationship of the principle parts. For the present we will assume that the two sides of the gear system are the inputs and the gear on the spider shaft is the output. Later we will show that any of these three gears can be either an input or an output.

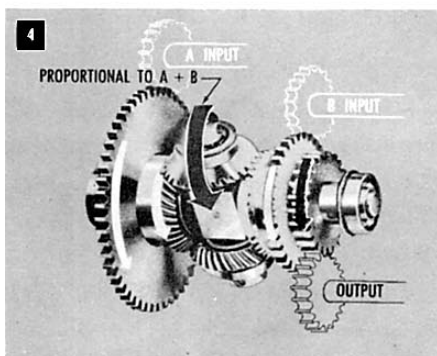
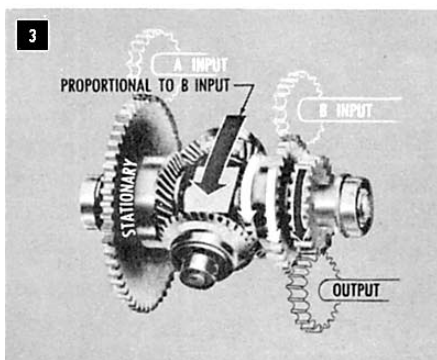
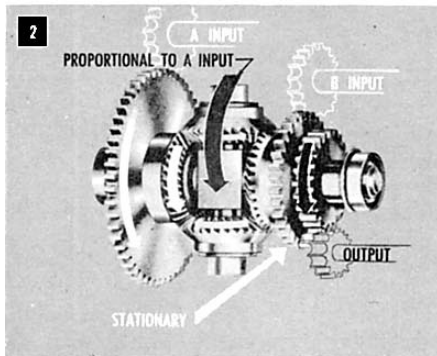
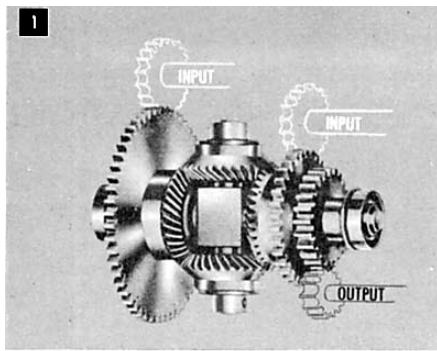


Figure 11-11.—How a differential works.

Now let's look at figure 11-11. In this hookup the two end gears are positioned by the input shafts, which represent the quantities to be added or subtracted. The spider gears do the actual adding and subtracting. They follow the rotation of the two end

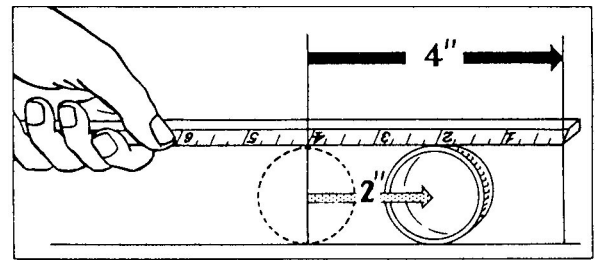


Figure 11-12.—The spider makes only half as many revolutions.

gears, turning the spider shaft several revolutions proportional to the sum, or difference, of the revolutions of the end gears.

Suppose the left side of the differential rotates while the other remains stationary, as in block 2 of figure 11-11. The moving end gear will drive the spider in the same direction as the input and, through the spider shaft and output gear, the output shaft. The output shaft will turn several revolutions proportional to the input.

If the right side is not rotated and the left side is held stationary, as in block 3 of figure 11-11, the same thing will happen. If both input sides of the differential turn in the same direction at the same time, the spider will be turned by both at once, as in block 4 of figure 11-11. The output will be proportional to the two inputs. Actually, the spider makes only half as many revolutions as the revolutions of the end gears, because the spider gears are free to roll between the end gears. To understand this better, let's look at figure 11-12. Here a ruler is rolled across the upper side of a cylindrical drinking glass, pushing the glass along a table top. The glass will roll only half as far as the ruler travels. The spider gears in the differential roll against the end gears in exactly the same way. Of course, you can correct the way the gears work by using a 2:1 gear ratio between the gear on the spider shaft and the gear for the output shaft. Very often, for design purposes, this gear ratio will be found to be different.

When two sides of the differential move in opposite directions, the output of the spider shaft is proportional to the difference of the revolutions of the two inputs. That is because the spider gears are free to turn and the two inputs drive them in opposite directions. If the two inputs are equal and opposite, the spider gears will turn, but the spider shaft will not move. If the two inputs turn in opposite directions for an unequal number of revolutions, the spider gears roll on the end gear that makes the lesser number of revolutions. That rotates the spider in the direction of the input making the greater number of revolution. The motion of the spider shaft

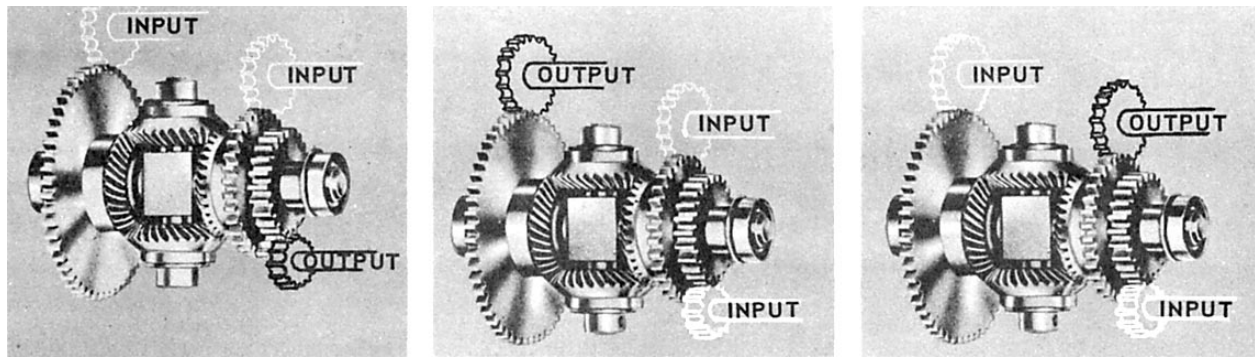


Figure 11-13.—Differential gear hookups.

will be equal to half the difference between the revolutions of the two inputs. A change in the gear ratio to the output shaft can then give us any proportional answer we wish.

We have been describing a hookup wherein the two sides are inputs and the spider shaft is the output. As long as you recognize that the spider follows the end gears for half the sum, or difference, of their revolutions, you don't need to use this type of hookup. You may use the spider shaft as one input and either of the sides as the other. The other side will then become the output. Therefore, you may use three different hookups for any given differential, depending on which is the most convenient mechanically, as shown in figure 11-13.

In chapter 13 of this book, we will describe the use of the differential gear in the automobile. Although this differential is similar in principle, you will see that it is somewhat different in its mechanical makeup.

LINKAGES

A linkage may consist of either one or a combination of the following basic parts:

1. Rod, shaft, or plunger
2. Lever
3. Rocker arm
4. Bell crank

These parts combined will transmit limited rotary or linear motion. To change the direction of a motion, we use cams with the linkage.

Lever-type linkages (fig. 11-14) are used in equipment that you open and close; for instance, valves in electric-hydraulic systems, gates clutches, and clutch-solenoid interlocks. Rocker

arms are merely a variation, or special use, of levers.

Bell cranks primarily transmit motion from a link traveling in one direction to another link moving in a different direction. The bell crank mounts on a fixed

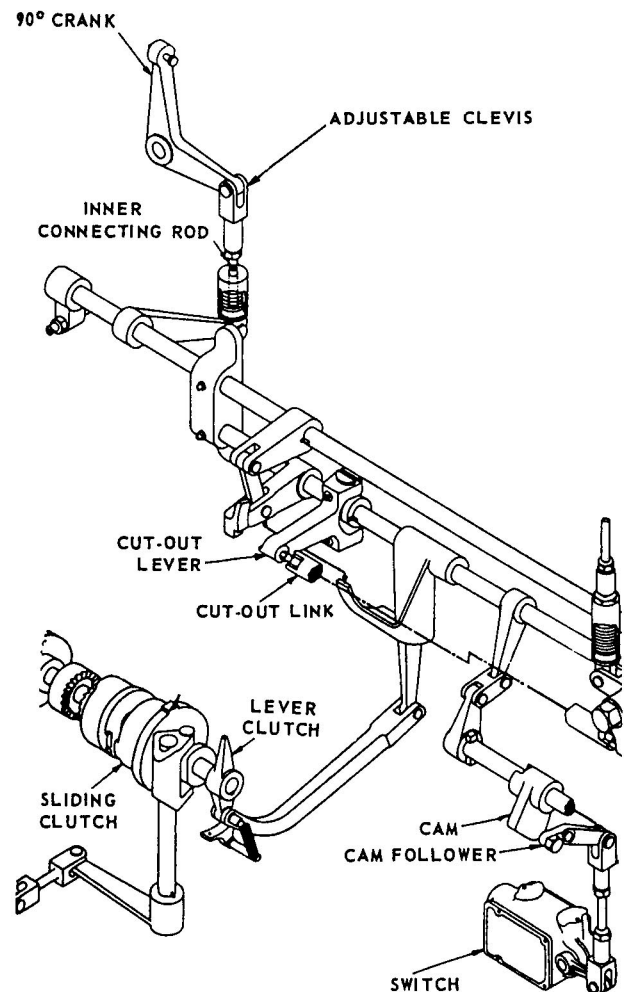


Figure 11-14.—Linkages.

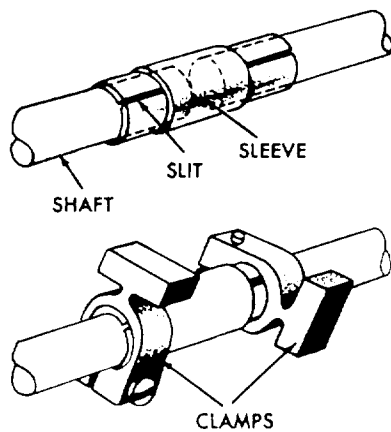


Figure 11-15.-Sleeve coupling.

pivot, and the two links connect at two points in different directions from the pivot. By properly locating the connection points, the output links can move in any desired direction.

All linkages require occasional adjustments or repair, particularly when they become worn. To make the proper adjustments, a person must be familiar with the basic parts that constitute a linkage. Adjustments are normally made by lengthening or shortening the rods and shafts by a clevis or turnbuckle.

COUPLINGS

The term *coupling* applies to any device that holds two parts together. Line shafts that make up several shafts of different lengths may be held together by any of several types of shaft couplings.

SLEEVE COUPLING

You may use the sleeve coupling (fig. 11-15) when shafts are closely aligned. It consists of a metal tube slit at each end. The slitted ends enable the clamps to fasten the sleeve securely to the shaft ends. With the clamps tightened, the shafts are held firmly together and turn as one shaft. The sleeve coupling also serves as a convenient device for making adjustments between units. The weight at the opposite end of the clamp from the screw merely offsets the weight of the screw and clamp arms. Distributing the weight evenly reduces the shaft vibration.

OLDHAM COUPLING

The Oldham coupling, named for its inventor, transmits rotary motion between shafts that are parallel but not always in perfect alignment.

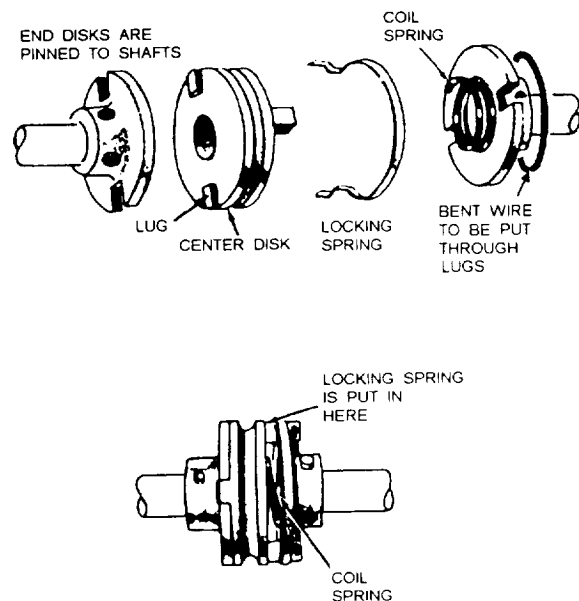


Figure 11-16.-Oldham coupling.

An Oldham coupling (fig. 11-16) consists of a pair of disks, one flat and the other hollow. These disks are pinned to the ends of the shafts. A third (center) disk, with a pair of lugs projecting from each face of the disk, fits into the slots between the two end disks and enables one shaft to drive the other shaft. A coil spring, housed within the center of the hollow end disk, forces the center disk against the flat disk. When the coupling is assembled on the shaft ends, a flat lock spring is slipped into the space around the coil spring. The ends of the flat spring are formed so that when they are pushed into the proper place, the ends of the spring push out and lock around the lugs. A lock wire is passed between the holes drilled through the projecting lugs to guard the assembly. The coil spring compensates for any change in shaft length. (Changes in temperature may cause the shaft length to vary.)

The disks, or rings, connecting the shafts allow a small amount of radial play. This play allows a small amount of misalignment of the shafts as they rotate. You can easily connect and disconnect the Oldham type couplings to realign the shafts.

OTHER TYPES OF COUPLINGS

We use four other types of couplings extensively in naval equipment:

1. The fixed (sliding lug) coupling, which is nonadjustable; it does allow for a small amount of misalignment in shafting (fig. 11-17).

2. The flexible coupling (fig. 11-18), which connects two shafts by a metal disk. Two coupling hubs,

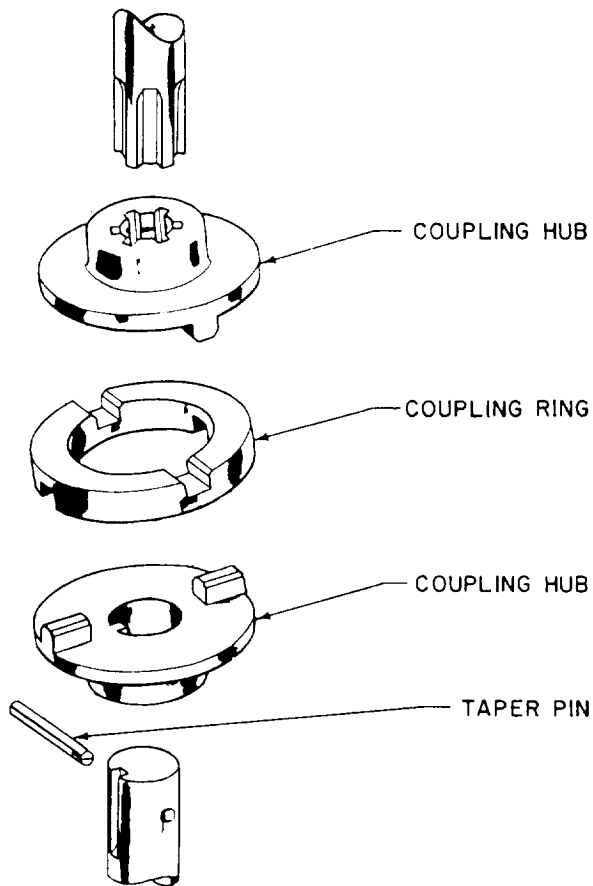


Figure 11-17.-Fixed coupling.

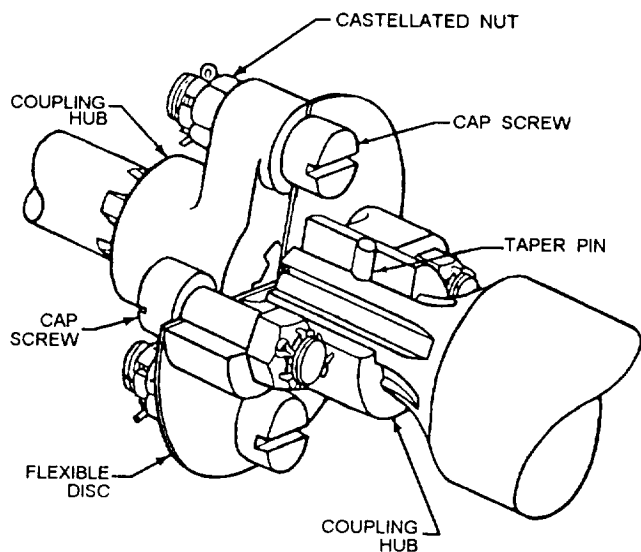


Figure 11-18.-Flexible coupling.

each splined to its respective shaft, are bolted to the metal disk. The flexible coupling provides a small amount of flexibility to allow for a slight axial misalignment of the shafts.

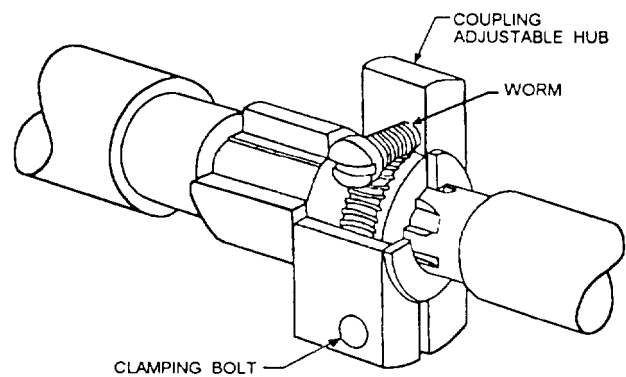


Figure 11-19.-Adjustable (vernier) coupling.

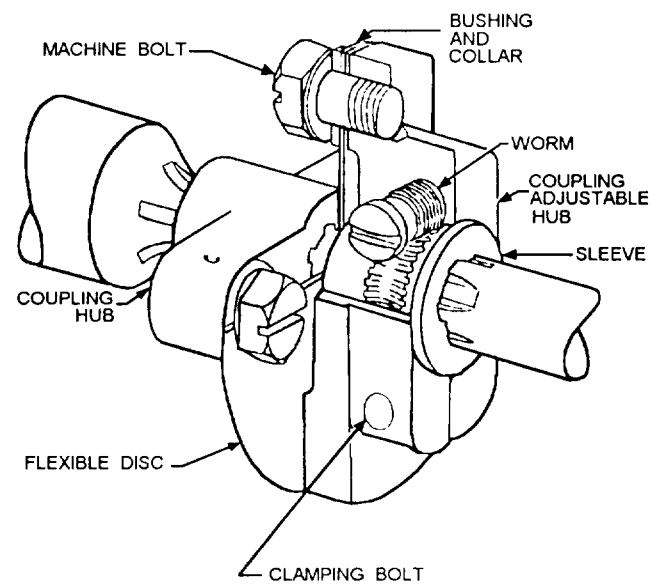


Figure 11-20.-Adjustable flexible (vernier) coupling.

3. The adjustable (vernier) coupling, which provides a means of finely adjusting the relationship of two interconnected rotating shafts (fig. 11-19). Loosening a clamping bolt and turning an adjusting worm allows one shaft to rotate while the other remains stationary. After attaining the proper relationship, you retighten the clamping bolt to lock the shafts together again.

4. The adjustable flexible (vernier) coupling (fig. 11-20), which is a combination of the flexible disk coupling and the adjustable (vernier) coupling.

UNIVERSAL JOINT

To couple two shafts in different planes, you need to use a universal joint. Universal joints have various

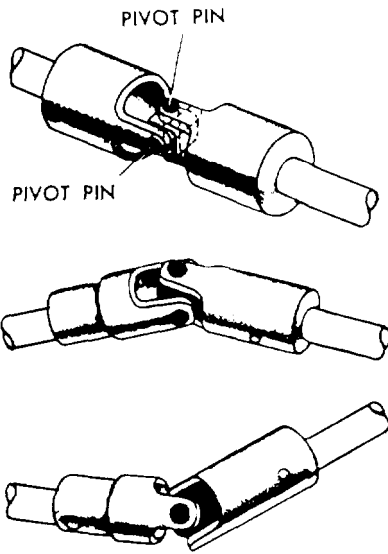


Figure 11-21.-Universal joint (Hooke type).

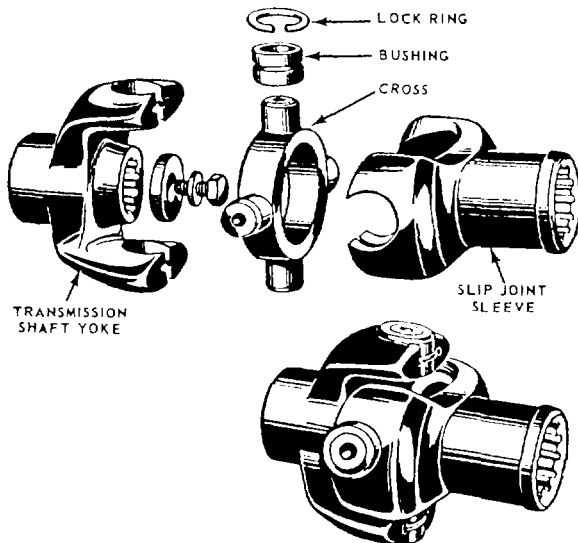


Figure 11-22.-Ring-and-trunnion universal joint.

forms. They are used in nearly all types and classes of machinery. An elementary universal joint, sometimes called a Hooke joint (fig. 11-21), consists of two U-shaped yokes fastened to the ends of the shafts to be connected. Within these yokes is a cross-shaped part that holds the yokes together and allows each yoke to bend, or pivot, in relation to the other. With this arrangement, one shaft can drive the other even though the angle between the two is as great as 25° from alignment.

Figure 11-22 shows a ring-and-trunnion universal joint. It is merely a slight modification of the old Hooke joint. Automobile drive shaft systems use two, and

sometimes three, of these joints. You will read more about these in chapter 13 of this book.

The Bendix-Weiss universal joint (fig. 11-23) provides smoother torque transmission but less structural strength. In this type of joint, four large balls transmit the rotary force, with a smaller ball as a spacer. With the Hooke type universal joint, a whipping motion occurs as the shafts rotate. The amount of whip depends on the degree of shaft misalignment. The Bendix-Weiss joint does not have this disadvantage; it transmits rotary motion with a constant angular velocity. However, this type of joint is both more expensive to manufacture and of less strength than the Hooke type.

CAMS

A cam is a rotating or sliding piece of machinery (as a wheel or a projection on a wheel). A cam transfers motion to a roller moving against its edge or to a pin free to move in a groove on its face. A cam may also receive motion from such a roller or pin. Some cams do not move at all, but cause a change of motion in the contacting part. Cams are not ordinarily used to transmit power in the sense that gear trains are used. They are used to modify mechanical movement, the power for which is furnished through other means. They may control other mechanical units, or they may synchronize or lock together two or more engaging units.

Cams are of many shapes and sizes and are widely used in machines and machine tools (fig. 11-24). We classify cams as

1. radial or plate cams,
2. cylindrical or barrel cams, and
3. pivoted beams.

A similar type of cam includes drum or barrel cams, edge cams, and face cams.

The drum or barrel cam has a path cut around its outside edge in which the roller or follower fits. It imparts a to-and-from motion to a slide or lever in a plane parallel to the axis of the cam. Sometimes we build these cams upon a plain drum with cam plates attached.

Plate cams are used in $5\frac{1}{32}$ and $3\frac{1}{50}$ guns to open the breechblock during counter-recoil.

Edge or peripheral cams, also called disc cams, operate a mechanism in one direction only. They rely on gravity or a spring to hold the roller in contact with the edge of the cam. The shape of the cam suits the action required.

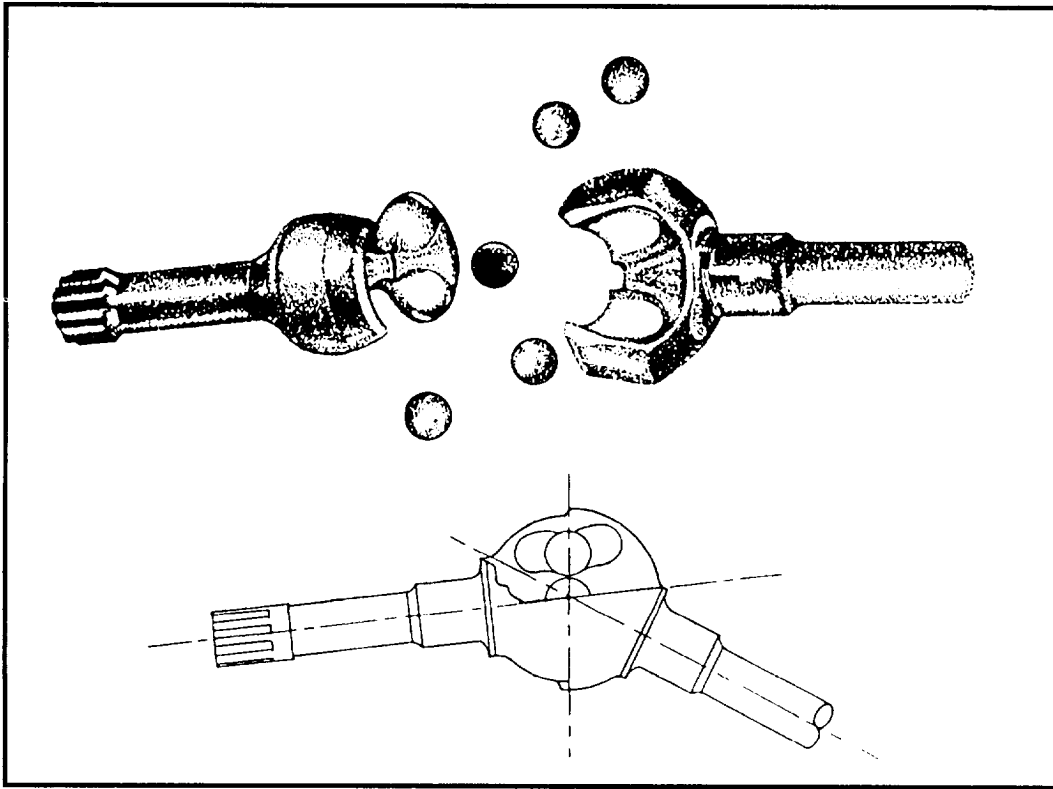


Figure 11-23.-Bendix-Weiss universal joint.

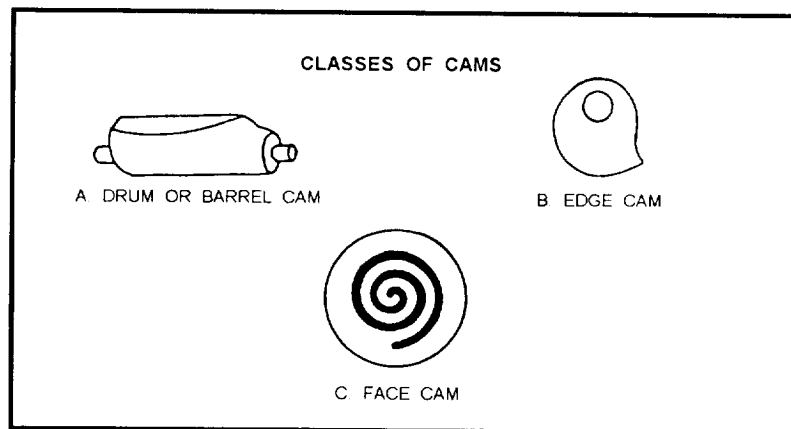


Figure 11-24.-Classes of cams.

Face cams have a groove or slot cut in the face to provide a path for the roller. They operate a lever or other mechanism positively in both directions. The roller is guided by the sides of the slot. Such a groove can be seen on top of the bolt of the Browning .30-caliber machine gun or in fire control cams. The shape of the

groove determines the name of the cam, for example, the square cam.

CLUTCHES

A clutch is a form of a coupling. It is designed to connect or disconnect a driving and a driven part as a

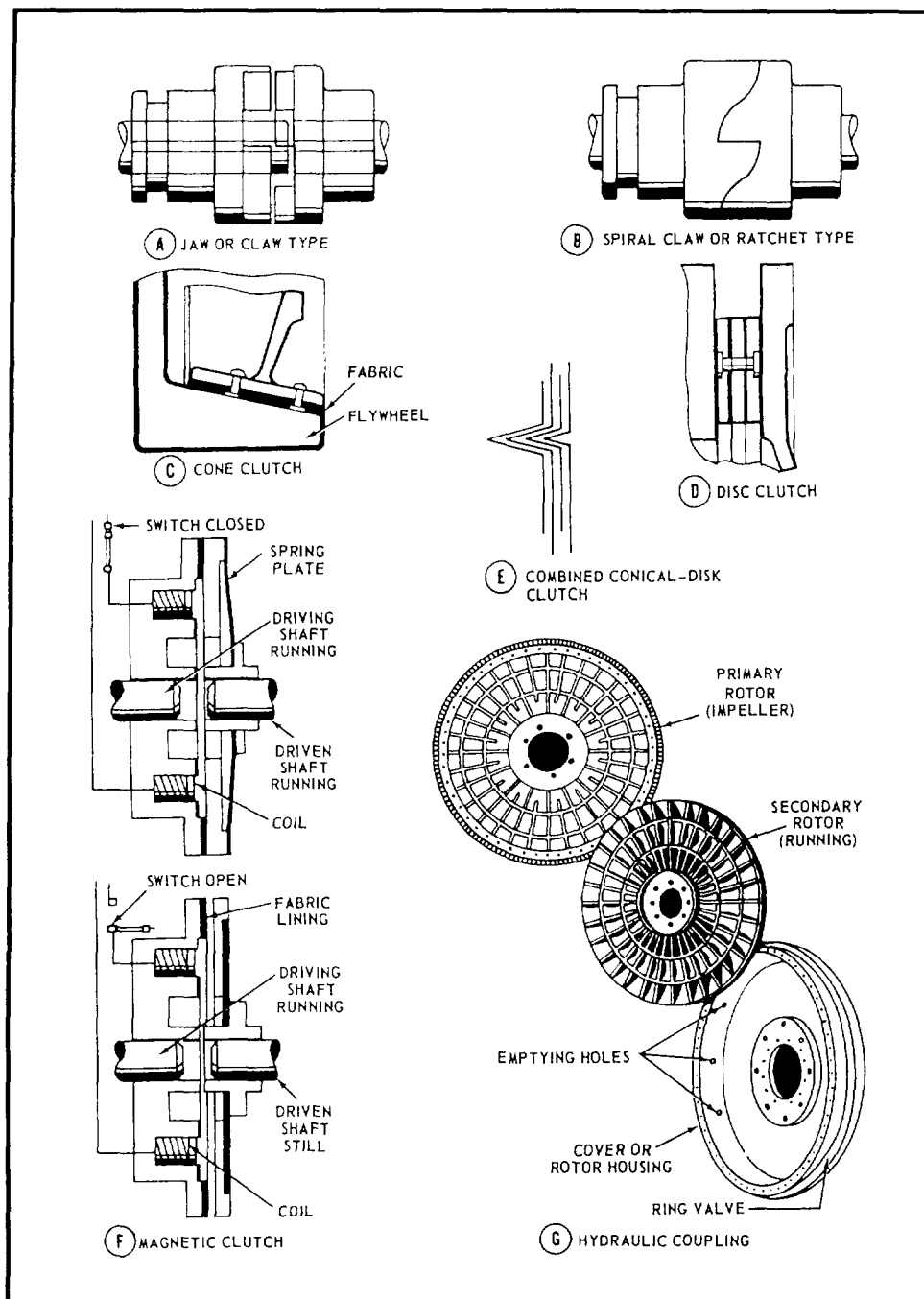


Figure 11-25. Types of clutches.

means of stopping or starting the driven part. There are two general classes of clutches: positive clutches and friction clutches.

Positive clutches have teeth that interlock. The simplest is the jaw or claw type (fig. 11-25, A), usable only at low speeds. The teeth of the spiral claw or ratchet type (fig. 11-25, B) interlock only one way—they cannot be reversed. An example of this type of clutch is

that seen in bicycles. It engages the rear sprocket with the rear wheel when the pedals are pushed forward and lets the rear wheel revolve freely when the pedals are stopped.

The object of a friction clutch is to connect a rotating member to one that is stationary, to bring it up to speed, and to transmit power with a minimum of slippage. Figure 11-25, C, shows a cone clutch commonly used

in motor trucks. Friction clutches may be single-cone or double-cone. Figure 11-25, D, shows a disc clutch, also used in autos. A disc clutch also may have several plates (multiple-disc clutch). In a series of discs, each driven disc is located between two driving discs. You may have had experience with a multiple-disc clutch on your car.

The Hele-Shaw clutch is a combined conical-disc clutch (fig. 11-25, E). Its groove permits cooling and circulation of oil. Single-disc clutches are frequently dry clutches (no lubrication); multiple-disc clutches may be dry or wet (either lubricated or operated with oil).

Magnetic clutches are a recent development in which the friction surfaces are brought together by magnetic force when the electricity is turned on (fig. 11-25, F). The induction clutch transmits power without contact between the driving and driven parts.

The way pressure is applied to the rim block, split ring, band, or roller determines the names of expanding clutches or rim clutches. In one type of expanding clutch, right- and left-hand screws expand as a sliding sleeve moves along a shaft and expands the band against the rim. The centrifugal clutch is a special application of a block clutch.

Machines containing heavy parts to be moved, such as a rolling mill, use oil clutches. The grip of the coil

causes great friction when it is thrust onto a cone on the driving shaft. Yet the clutch is very sensitive to control.

Diesel engines and transportation equipment use pneumatic and hydraulic clutches. Hydraulic couplings (fig. 11-25, G), which also serve as clutches, are used in the hydraulic A-end of electric-hydraulic gun drives.

SUMMARY

In this chapter we discussed the following elements and mechanisms used in naval machinery:

Two types of bearings are used in naval machinery: sliding and antifrictional.

Springs are another element used in machinery. Springs can be twisted, pulled, or stretched by force and can return to their original shape when the force is released.

One basic mechanism of machines is the gear differential. A gear differential is a mechanism that is capable of adding and subtracting mechanically. Other basic mechanisms include linkages, couplings, cams and cam followers, and clutches.

